

AIR RESOURCES BRANCH

Technology Development and Appraisal Section
Special Studies and Program Planning

Report #ARB-TDA-45-78

PRESSURE DROP MEASUREMENTS ACROSS
VARIOUS FILTER MEDIA SUITABLE FOR AIR POLLUTION
STUDIES

(Supplement to Report #ARB-TDA-44-78)

* Mention of tradenames or commercial
products in this report does not
constitute an endorsement.

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01. SUMMARY:

This report is a supplement to report #ARB-TDA-44-78 entitled, "Review of Filter Media for Air Pollution Studies". Measurement of the pressure drop across a filter can be a useful tool in designing an effective sampling train, or estimating the loading capacities of a sampling train, or relating the pressure drop across a filter to the volumetric flow rate through it. Experiments were performed in 1976 and 1977 to measure the pressure drop across 13 types of filters suitable for air sampling. Appendix A is an extensive compilation of the results.

02. CONCLUSIONS:

- (1) The pressure drop and flow rate are essentially directly proportional for any given filter. Measurements of one will determine the other with the right calibration curve.
- (2) Both the linear and 2nd degree curves fit the data points with virtually equal accuracy. These curves, then, describe the relationship of pressure drop versus flow rate for 13 filter types.
- (3) High correlation coefficients were obtained for all of the valid data which were produced by several independent experimenters.

03. INTRODUCTION:

The pressure difference across an orifice, filter or sampling system is an important element in the performance capabilities of a particular sampling train. Since pressure drops across consecutive elements may be approximately additive in such a system, the sum may determine the choice of air mover when designing a sampling train. The pressure drop across the filter may determine the size of filter to be used (i.e., 8" x 10", 47 mm), the design of the system after it, and the capacity of the pump required to pull the desired flow rate through the entire sampling system (including the effect of particulate loading).

The pressure drop across a filter or orifice is related to the volumetric flow rate through it so flows can be determined directly and accurately by use of a manometer and calibration chart. Manometers are less expensive than sensitive flow measuring devices and they can be made portable for easy use in the field.

04. EXPERIMENTAL PROCEDURE:

The change of pressure downstream of the filter relative to atmosphere was determined at various flow rates for 6 different brands of filters with several different types and pore sizes.

The filters tested are:

Nuclepore	0.2 um pore size
	0.4 um pore size
	0.8 um pore size
	8.0 um pore size
Millipore	Type "HA"; 0.4 um pore size
	Type "AA"; 0.8 um pore size
	Type "RA"; 1.2 um pore size
	Type "LS"; 5.0 um pore size
Whatman	Type #41
	Type #40
Glass Fibre	General Metals

Delbag Microsorban

Gelman Tuffryn, 0.45 um pore size

A Nuclepore 47 mm two-stage filter holder (Cat. No. FH M47 PL 002 01) was modified to reduce significantly the pressure drop across the apparatus itself, and a teflon tap was inserted immediately downstream of the prefilter support screen. The internal pressure directly behind the filter was measured by a mercury manometer open to the atmosphere. The effective area of filtration was measured by a scanning electron microscope to be 12.25 cm^2 . The flow rate was measured by a Hastings mass flowmeter (50 K sccm $\pm 1\%$ deviation full scale) with the output displayed on a Fluke digital multimeter. The air mover used was a Gast oil vane, high vacuum pump capable of maintaining a static vacuum of 680 torr. A standard hose clamp placed behind the filter holder but in front of the flow meter was used to alter the flow. Figure 1 depicts the apparatus.

The experiments were run in laboratory facilities where the relatively clean air kept loading of the filters to a minimum. An extensive number of filters was measured during three different periods; August 1976, January 1977 and August 1977. Three operators were involved in performing the experiments including a supervisor who scrutinized all runs. Leak checks were performed regularly during each day of operation. The procedure of operation was relatively simple for each run; the hose was crimped and simultaneous readings from the multimeter and manometer were obtained. Attention was paid to detail including the order of events to be followed. Individual measurement runs for each filter were no longer than 2-5 minutes (to minimize loading) during which time at

least 5 points at equally spaced flow intervals were obtained. The number of runs performed for each filter is outlined in Table 1.

05. RESULTS:

The curves of pressure drop versus flow rate for various filters are presented in Appendix A. These results have been calculated per square centimeter of filter area so that flows may be estimated for any filter size from the graph.

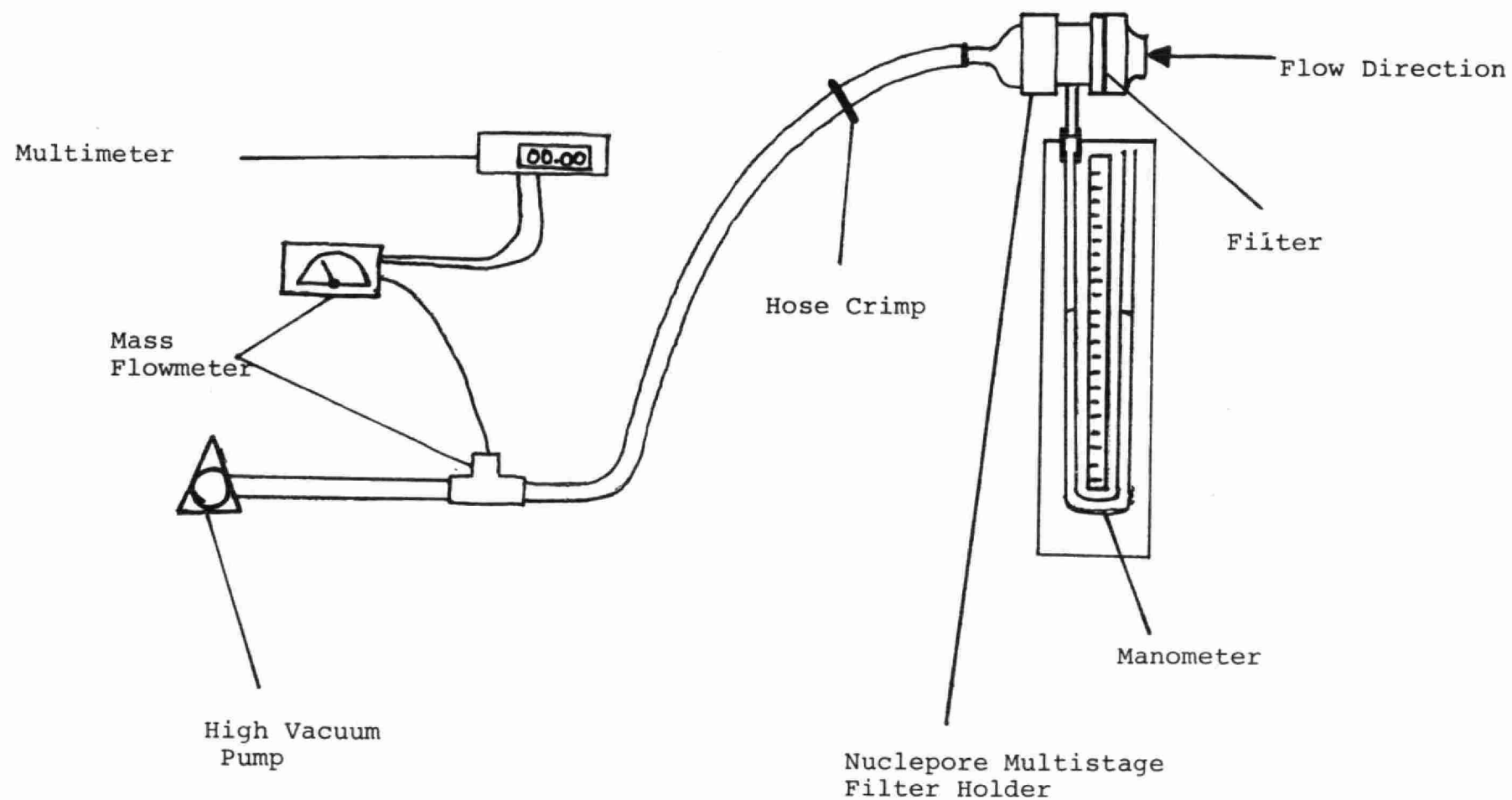
The series of experiments run during August 1976 produced well-defined regression lines having high correlation coefficients for each filter type, but a second series was run in January 1977 by another operator to see if the results were reproducible. Although the results obtained correlated equally well for each filter type, the curves consistently showed a much higher pressure drop for the corresponding flow rate (steeper slope) than the data from the first series of experiments. Consequently the data were not comparable and a systematic experimental error was suspected. There were minor differences in procedure including the use in the second set of experiments of a Wallace-Tiernan gauge instead of a mercury manometer to measure pressure drop. A third series of experiments was performed during August 1977 involving the original operator/supervisor and a third experimenter. Curves developed by the third operator correlated closely to those obtained in August 1976. Experiments were performed to check the minor alterations in procedure, but the major differences of the January 1977 study could not be accounted for. The Wallace-Tiernan(diaphragm) gauge was not available for the third set of experiments and thus could not be compared directly to the mercury manometer. A pressure drop across the length of the tubing used to connect the diaphragm gauge is the suspected source of

TABLE 1.

DATA BASE

FILTER BRAND	FILTER TYPE	NO. FILTERS MEASURED	TOTAL NO. OF POINTS
Nuclepore	0.2 um pore size	8	35
Nuclepore	0.4 um pore size	28	136
Nuclepore	0.8 um pore size	9	47
Nuclepore	8.0 um pore size	8	42
Millipore	"HA"	6	30
Millipore	"AA"	3	14
Millipore	"RA"	8	47
Millipore	"LS"	11	58
Watman	40	1	6
Watman	41	3	15
Delbag	Microsorban	10	59
Gelman	Tuffryn	10	53
Glass Fibre		12	65

FIGURE 1: Experimental Apparatus



error. Consequently, because of a systematic experimental error, the January 1977 data were discarded. The results are plotted in Appendix A.

Linear (first degree) and second degree regression lines were computed for every filter type. The coefficients of determination for both regressions are displayed at the end of the data sheets including the standard error which relates only to the linear regression.

06. DISCUSSION:

Although both the 1st degree and 2nd degree curves are plotted using the same data, the linear correlation coefficient and r^2 term for the 2nd degree fit indicate that both curves fit the data with acceptable accuracy. The difference is usually less than 1% between the two values and all curves but one (92% of the data) have correlation coefficients greater than 0.97. Noticeable trends between the two curves on each graph imply subjectively that the 2nd degree curve fits the data better than the linear 1st degree. For example, in every graph the 2nd degree curve intersects the Y axis closer to the origin than the linear counterpart. Also, in many of the cases, most of the points plotted for individual graphs lie below the linear regression in the low and high range of the curve but above the line in the middle range whereas the 2nd degree curve goes through the center of more clusters of points.

Comparisons between the experimental data and published pressure drop measurements showed close agreement with several authors,⁽¹⁾⁽⁴⁾ but inaccuracies in reading some graphs made it very difficult to draw any definite conclusions.⁽²⁾⁽³⁾

The flow rate for any filter listed can be determined by obtaining the $\mu\text{pm cm}^{-2}$ value from the graph and multiplying it by the exposed surface area of the filter. The exposed area of a Hi-Vol filter cartridge is 406.5 cm^2 . The exposed area of the Millipore 47 mm filter holder is 9.6 cm^2 and 12.25 cm^2 for the Nuclepore filter holder as measured by MOE laboratories under the scanning electron microscope.

07. BIBLIOGRAPHY:

- (1) Lui, B.Y.H., Lee, K.W., "Efficiency of Membrane and Nuclepore Filters for Submicron Aerosols", Environmental Science and Technology; Volume 10, Number 4, April 1976.
- (2) Jacko, M.G., DuCharme, R.T., "Brake Emissions: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources", Bendix Research Laboratories, NTIS Report No. PB-222 372, March 1973, (Appendix B).
- (3) Spurny, K.R., Lodge, J.P. Jr., Frank, E.R., Sheesley, D.C., "Aerosol Filtration by Means of Nuclepore Filters: Structural and Filtration Properties"; Environmental Science and Technology, Volume 3 Number 5, May 1969.
- (4) Lippmann, M., "Filter Media and Filter Holders for Air Sampling", Air Sampling Instruments for Evaluation of Atmospheric Contaminants; Published by American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio. 1972.

08. APPENDIX A.

Data For 0.2 μ m Pore Size Nuclepore Filter

NO. POINTS = 35

X: MEAN= 289.9714286 ST.DEV.= 156.1474578
Y: MEAN= 1.171714286 ST.DEV.= 0.599732714

CORR. COEFF. = 0.995616380

COEFFICIENTS

B(0)= 0.0629
B(1)= 0.0038

R SQUARE = 0.991251977

STANDARD ERROR OF Y ON X IS 0.056937080

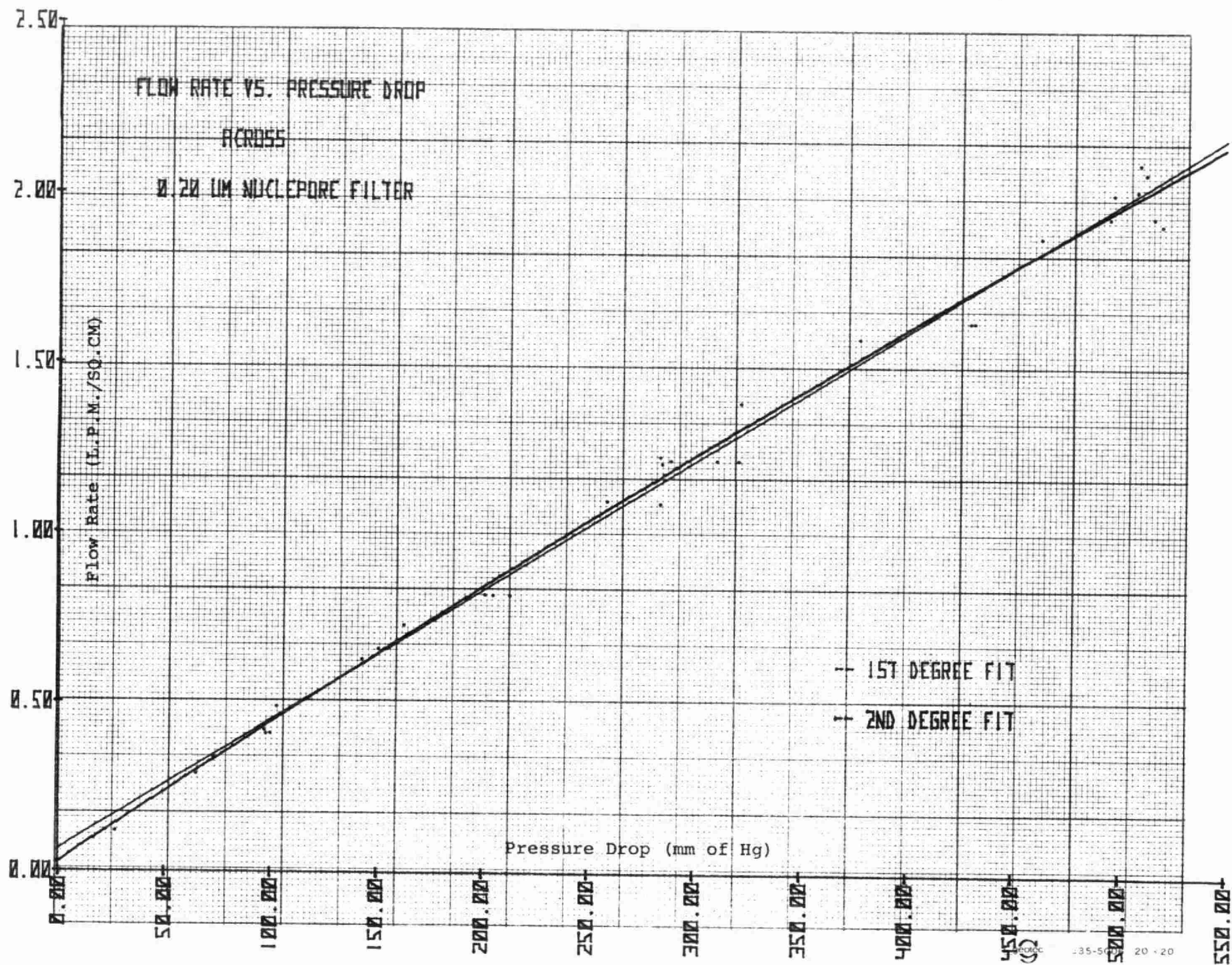
COEFFICIENTS

B(0)= 0.0227
B(1)= 0.0042
B(2)= -0.0000

R SQUARE = 0.991727890

1st DEGREE

2nd DEGREE



Data For 0.40 μm Pore Size Nuclepore Filter

NO. POINTS = 136

X: MEAN= 168.9558824 ST.DEV.= 92.05456254
Y: MEAN= 2.501544118 ST.DEV.= 1.272129087

CORR. COEFF. = 0.986432316

COEFFICIENTS

B(0) = 0.1984
B(1) = 0.0136

R SQUARE = 0.973048714

1st DEGREE

Standard Error
Y on X
.21 lpm cm^{-2}

NO. POINTS = 136

X: MEAN= 168.9558824 ST.DEV.= 92.05456254
Y: MEAN= 2.501544118 ST.DEV.= 1.272129087

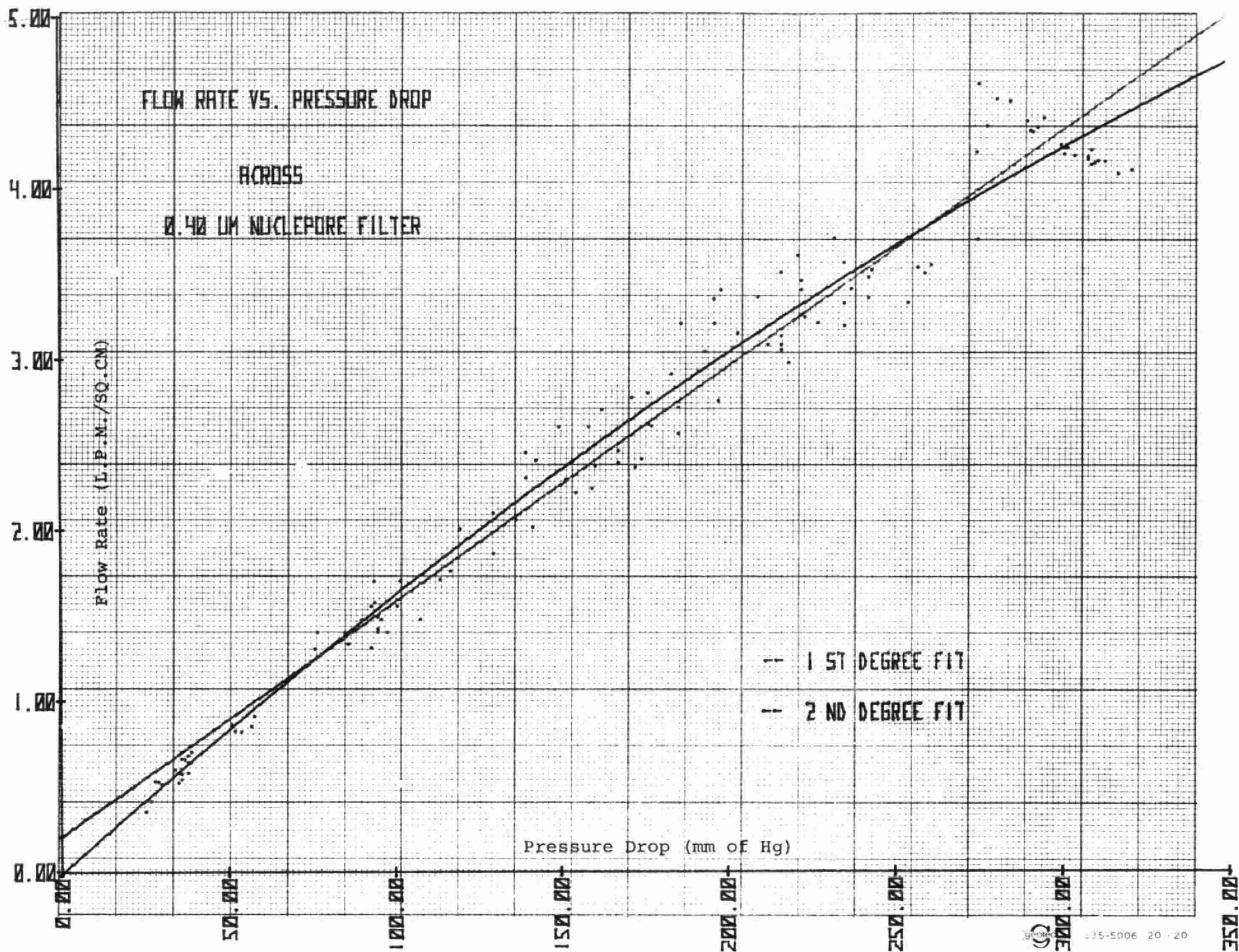
CORR. COEFF. = 0.986432316

COEFFICIENTS

B(0) = -0.0291
B(1) = 0.0174
B(2) = -0.0000

R SQUARE = 0.977240801

2nd DEGREE



Data For 0.8 μ m Pore Size Nuclepore Filter

NO. POINTS = 47

X: MEAN= 80.12765957 ST.DEV.= 51.31556973
Y: MEAN= 3.267446809 ST.DEV.= 1.974583575

CORR. COEFF.= 0.989487057

COEFFICIENTS

B(0)= 0.2166
B(1)= 0.0381

R SQUARE = 0.979084635

1st DEGREE

Standard Error
Y on X
.29 lpm cm⁻²

NO. POINTS = 47

X: MEAN= 80.12765957 ST.DEV.= 51.31556973
Y: MEAN= 3.267446809 ST.DEV.= 1.974583575

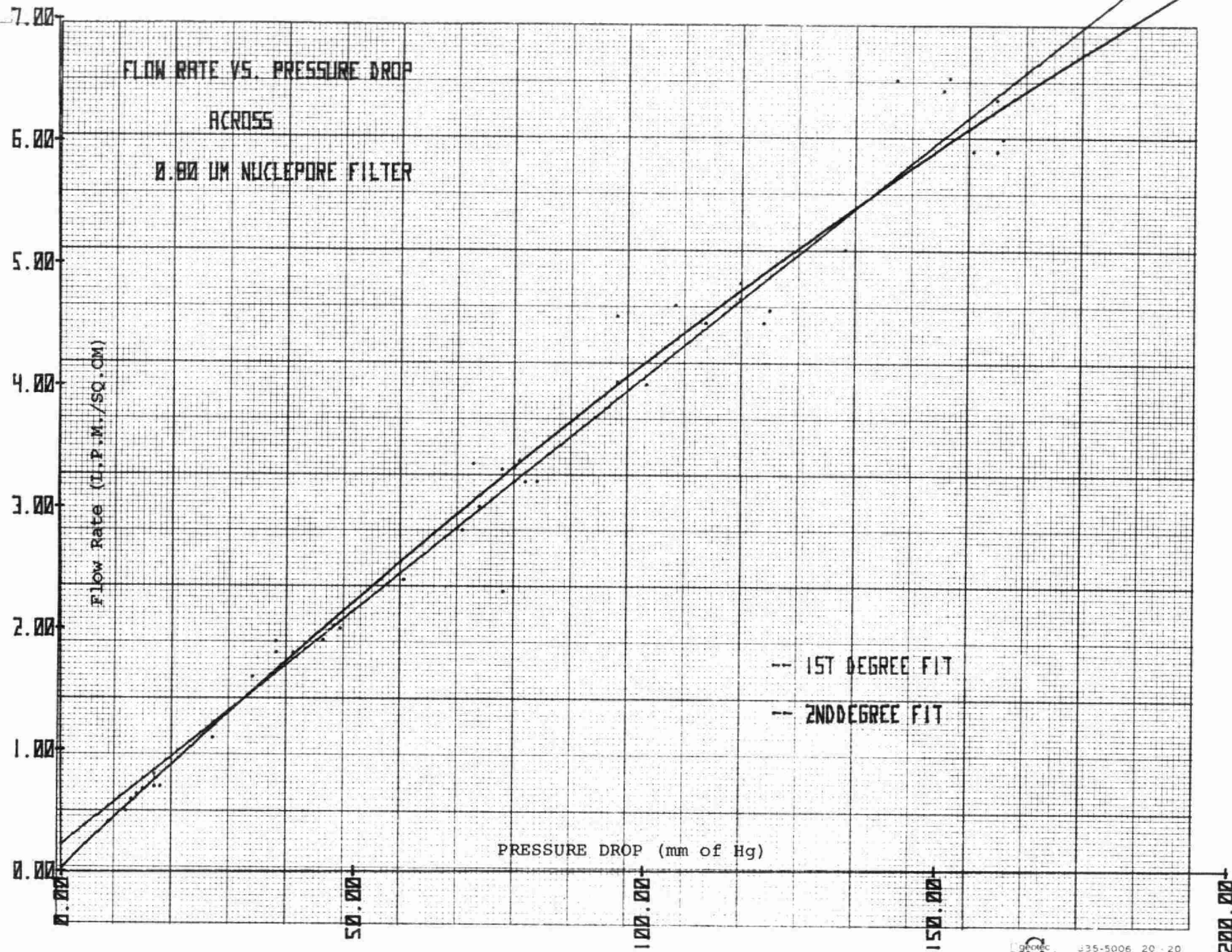
CORR. COEFF.= 0.989487057

COEFFICIENTS

B(0)= 0.0638
B(1)= 0.0436
B(2)= -0.0000

R SQUARE = 0.980438634

2nd DEGREE



Data For 8.0 μ m Pore Size Nuclepore Filter

NO. POINTS = 42

X: MEAN= 21.54761905 ST.DEV.= 14.54212113
Y: MEAN= 3.871190476 ST.DEV.= 2.375994993

CORR. COEFF. = 0.988882318

COEFFICIENTS

B(0) = 0.3897
B(1) = 0.1616

R SQUARE = 0.977888239

1st DEGREE

Standard Error
Y on X
.36 lpm cm⁻²

NO. POINTS = 42

X: MEAN= 21.54761905 ST.DEV.= 14.54212113
Y: MEAN= 3.871190476 ST.DEV.= 2.375994993

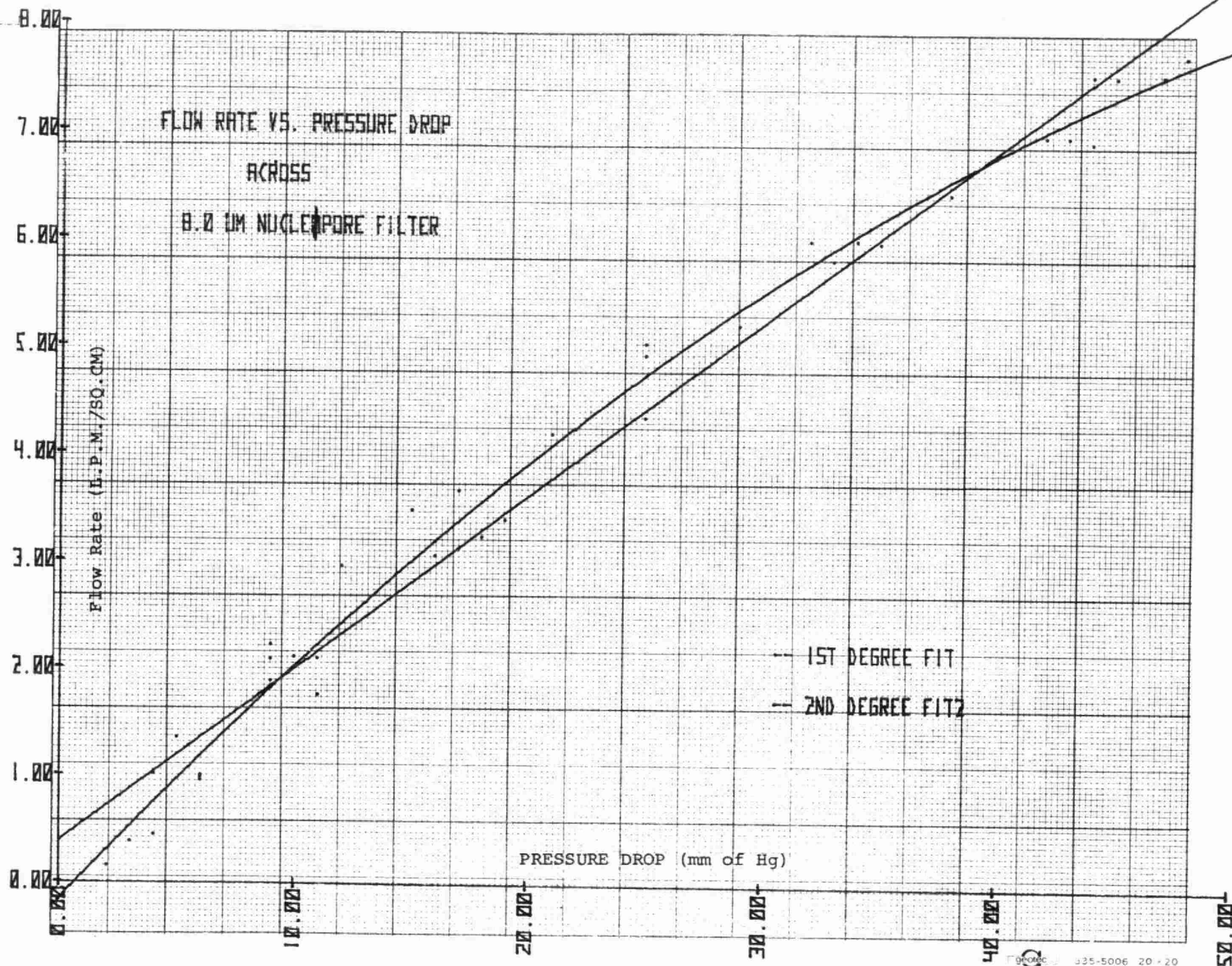
CORR. COEFF. = 0.988882318

COEFFICIENTS

B(0) = -0.1730
B(1) = 0.2333
B(2) = -0.0015

R SQUARE = 0.988741536

2nd DEGREE



Data For Millipore Type "HA" Filter

(0.45 μm pore size)

NO. POINTS = 30

X: MEAN= 234.6333333 ST.DEV.= 144.7319719

Y: MEAN= 1.715666667 ST.DEV.= 0.961212178

CORR.COEFF.= 0.991948409

COEFFICIENTS

B(0)= 0.1699

B(1)= 0.0066

R SQUARE = 0.983961645

NO. POINTS = 30

X: MEAN= 234.6333333 ST.DEV.= 144.7319719

Y: MEAN= 1.715666667 ST.DEV.= 0.961212178

CORR.COEFF.= 0.991948409

COEFFICIENTS

B(0)= -0.0242

B(1)= 0.0091

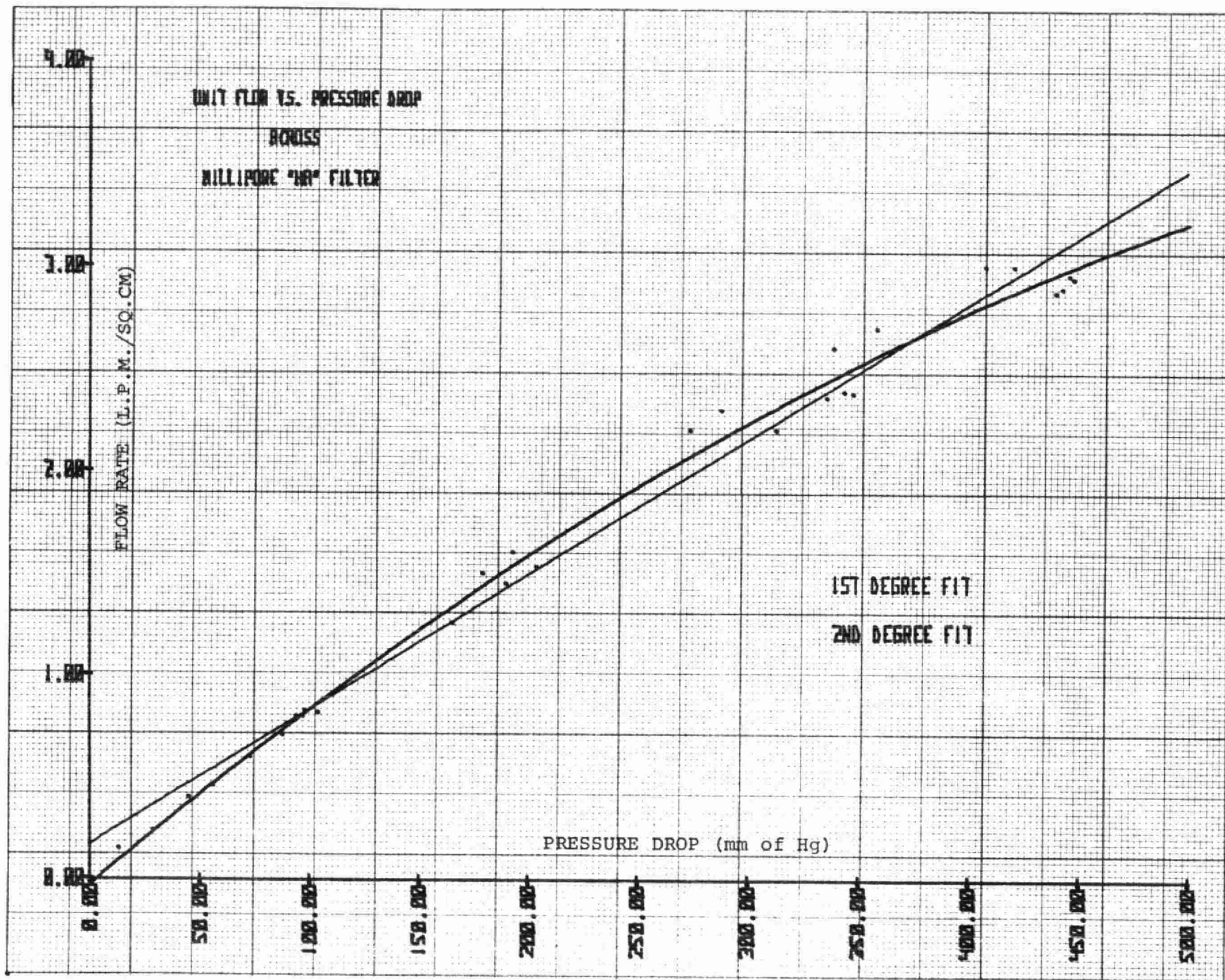
B(2)= -0.0000

R SQUARE = 0.991554612

Standard Error
.12 lpm cm^{-2}

1st DEGREE

2nd DEGREE



Data For Millipore Type "AA" Filter

(0.8 μm pore size)

NO. POINTS = 14

X: MEAN= 113.9285714 ST.DEV.= 72.40108827

Y: MEAN= 2.215 ST.DEV.= 1.323385809

CORR.COEFF.= 0.998149915

COEFFICIENTS

B(0)= 0.1364

B(1)= 0.0182

R SQUARE = 0.996303253

NO. POINTS = 14

X: MEAN= 113.9285714 ST.DEV.= 72.40108827

Y: MEAN= 2.215 ST.DEV.= 1.323385809

CORR.COEFF.= 0.998149915

COEFFICIENTS

B(0)= -0.0042

B(1)= 0.0218

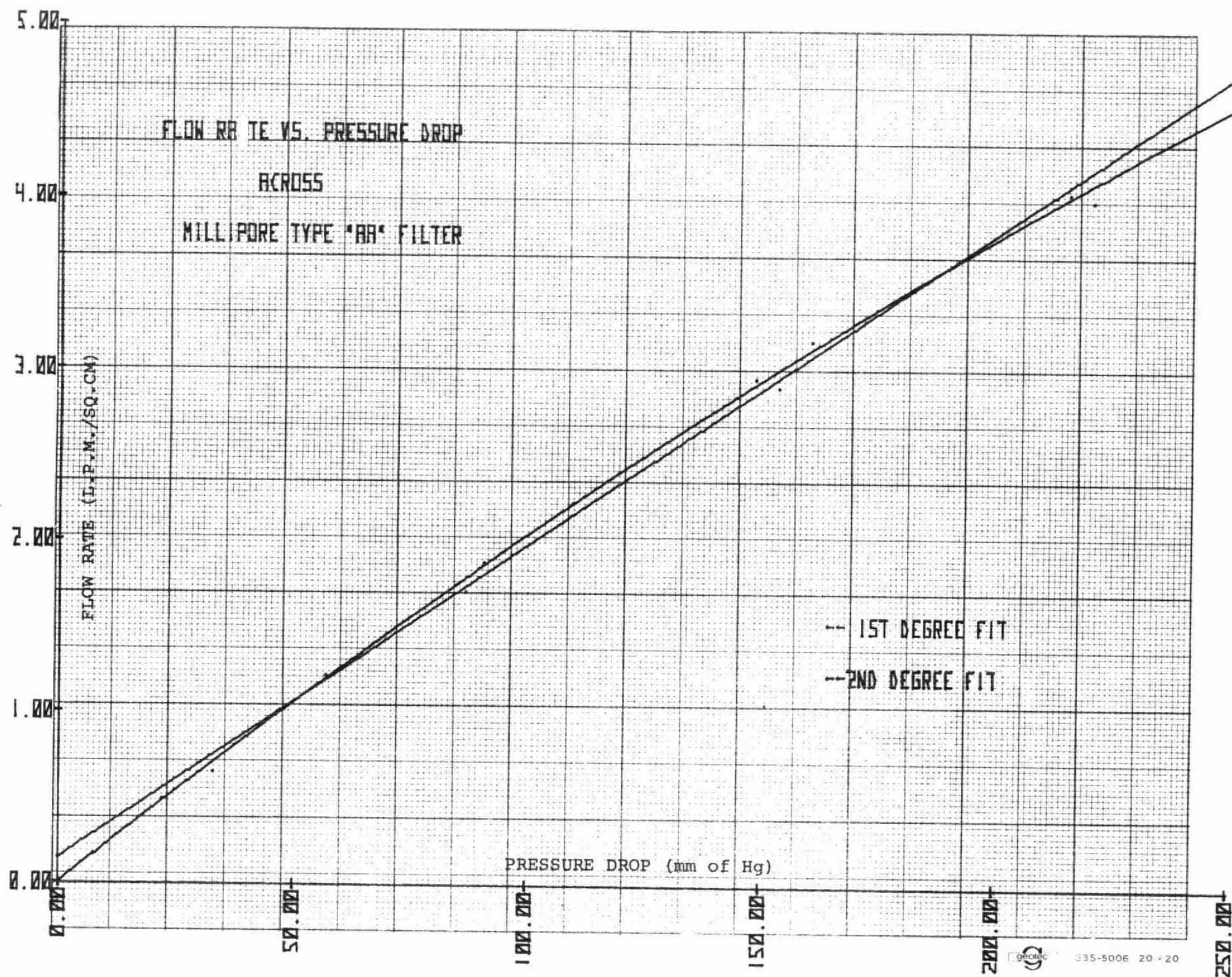
B(2)= -0.0000

R SQUARE = 0.998370641

Standard Error
.08 lpm cm^{-2}

1st DEGREE

2nd DEGREE



Data For Millipore Type "LS" Filter
(5.0 μm pore size)

NO. POINTS = 58

X: MEAN= 123.3620690 ST.DEV.= 81.67923962
Y: MEAN= 2.771206897 ST.DEV.= 1.552798354

CORR.COEFF.= 0.990952969

COEFFICIENTS

B(0)= 0.4472
B(1)= 0.0188

R SQUARE = 0.981987786

NO. POINTS = 58

X: MEAN= 123.3620690 ST.DEV.= 81.67923962
Y: MEAN= 2.771206897 ST.DEV.= 1.552798354

CORR.COEFF.= 0.990952969

COEFFICIENTS

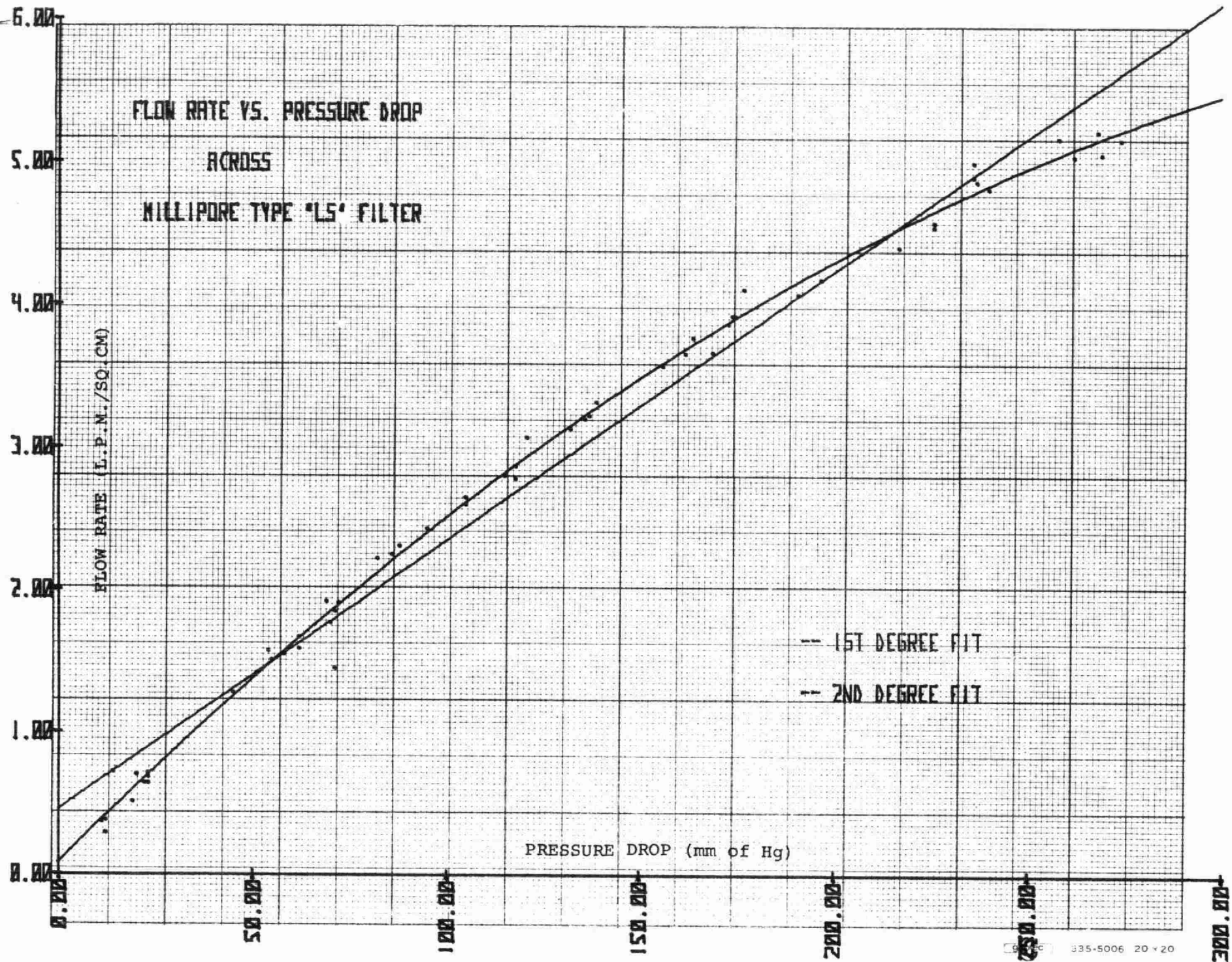
B(0)= 0.0812
B(1)= 0.0273
B(2)= -0.0000

R SQUARE = 0.995937724

Standard Error
Y on X
.21 lpm cm^{-2}

1st DEGREE

2nd DEGREE



Data For Millipore Type "RA" Filter
(1.2 μm pore size)

NO. POINTS = 47

X: MEAN= 93.40425532 ST.DEV.= 51.34396352
Y: MEAN= 3.27 ST.DEV.= 1.657269887

CORR.COEFF.= 0.961338741

COEFFICIENTS

B(0)= 0.3717
B(1)= 0.0310

R SQUARE = 0.924172174

NO. POINTS = 47

X: MEAN= 93.40425532 ST.DEV.= 51.34396352
Y: MEAN= 3.27 ST.DEV.= 1.657269887

CORR.COEFF.= 0.961338741

COEFFICIENTS

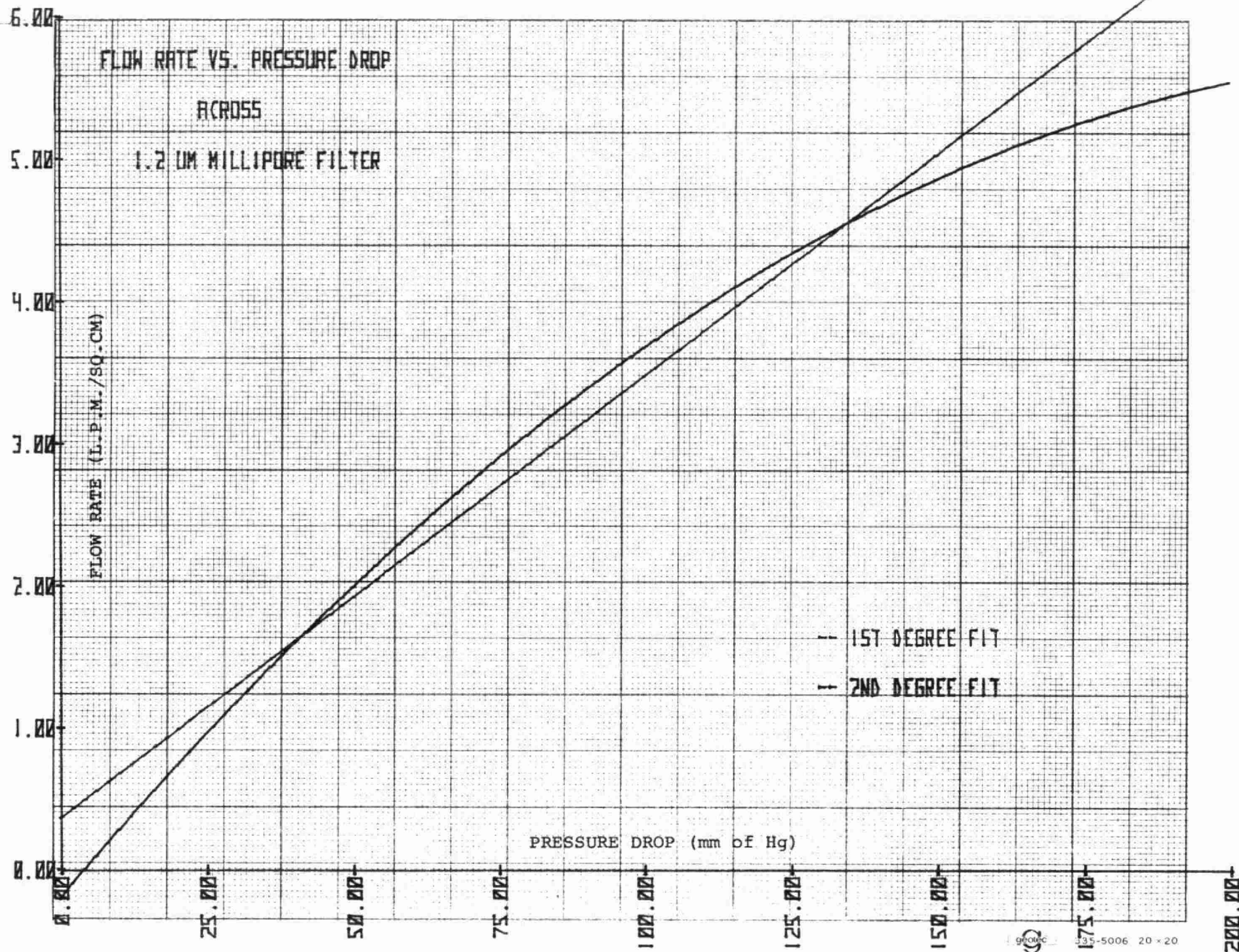
B(0)= -0.1962
B(1)= 0.0468
B(2)= -0.0001

R SQUARE = 0.940185608

Standard Error
Y on X
.46 lpm cm^{-2}

1st DEGREE

2nd DEGREE



Data For Delbag Filter

NO. POINTS = 59

X: MEAN= 39.61830508 ST.DEV.= 24.51914749
Y: MEAN= 3.230288136 ST.DEV.= 1.838544609

CORR.COEFF.= 0.99469868

COEFFICIENTS

B(0)= 0.2753
B(1)= 0.0746

R SQUARE = 0.98942546

NO. POINTS = 59

* MEAN= 39.61830508 ST.DEV.= 24.51914749
* MEAN= 3.230288136 ST.DEV.= 1.838544609

CORR.COEFF.= 0.99469868

COEFFICIENTS

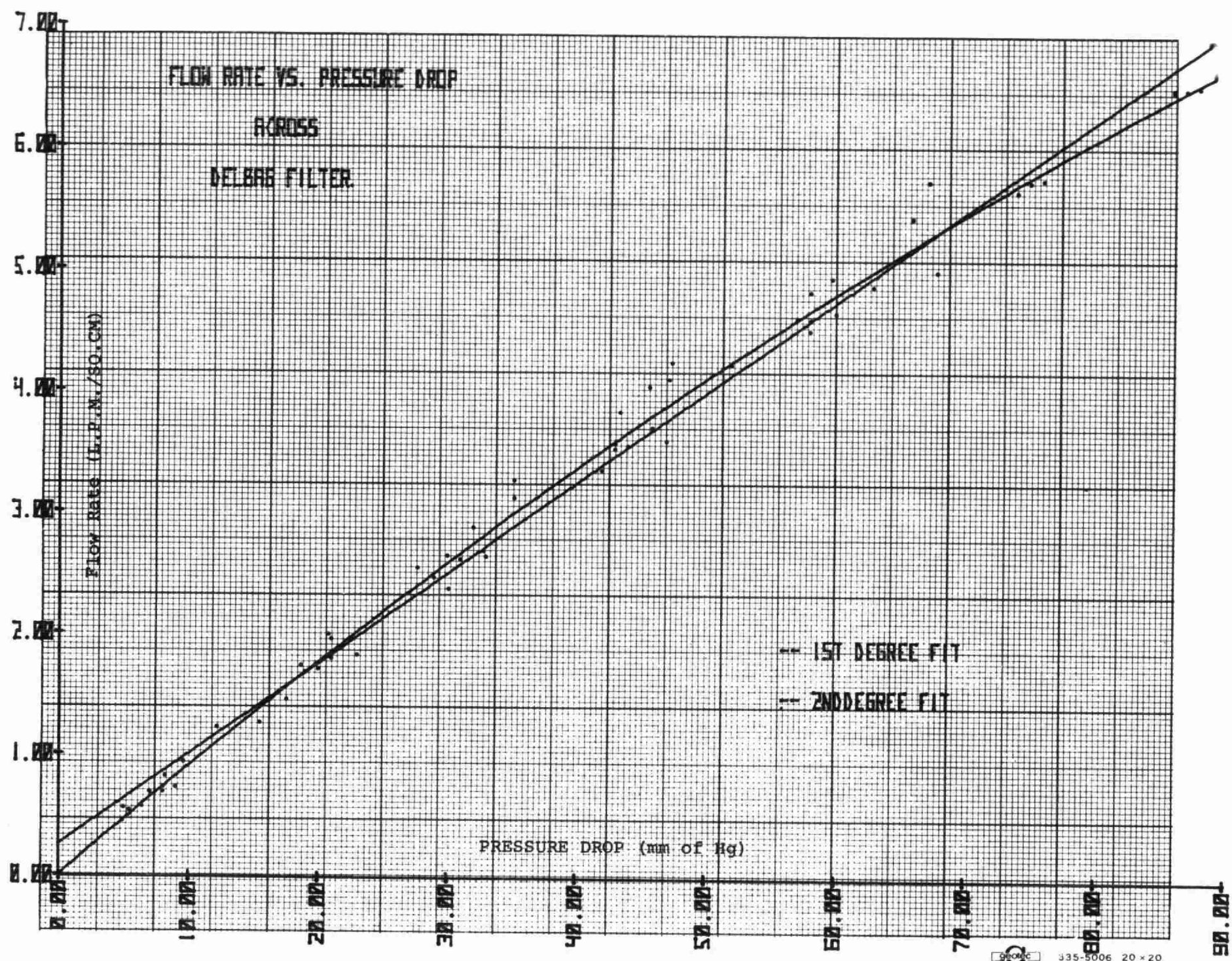
(0)= 0.0199
(1)= 0.0919
(2)= -0.0002

R SQUARE = 0.993380556

Standard Error
Y on X
.19 lpm cm⁻²

1st DEGREE

2nd DEGREE



Data For Gelman Type "Tuffryn" Filter
(0.45 μm pore size)

NO. POINTS = 53

X: MEAN= 232.9433962 ST.DEV.= 133.8307506
Y: MEAN= 1.727735849 ST.DEV.= 0.927572600

CORR. COEFF. = 0.993794248

COEFFICIENTS

B(0) = 0.1232
B(1) = 0.0069

R SQUARE = 0.987627008

NO. POINTS = 53

X: MEAN= 232.9433962 ST.DEV.= 133.8307506
Y: MEAN= 1.727735849 ST.DEV.= 0.927572600

CORR. COEFF. = 0.993794248

COEFFICIENTS

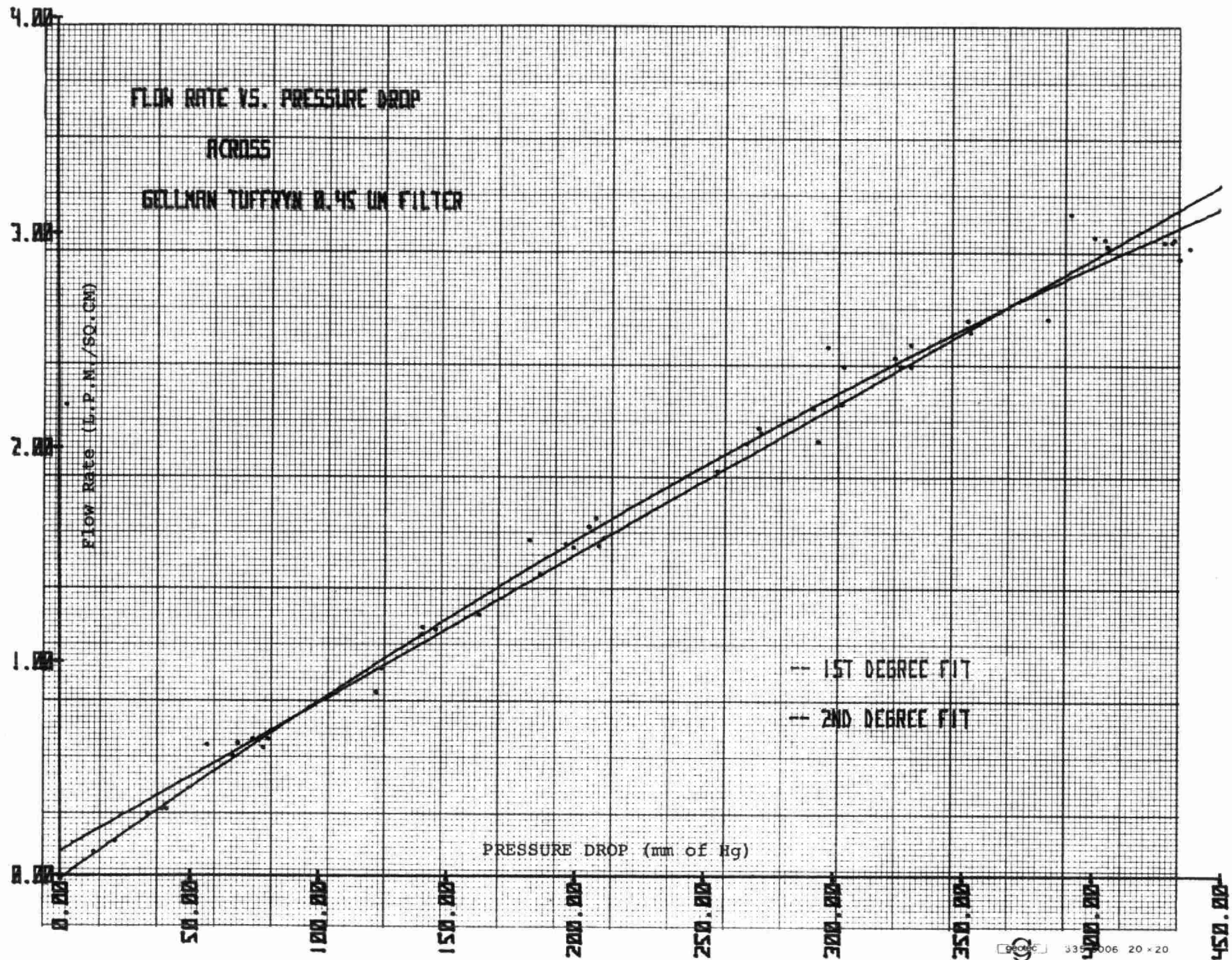
B(0) = -0.0113
B(1) = 0.0086
B(2) = -0.0000

R SQUARE = 0.991251061

Standard Error
Y on X
.10 lpm cm^{-2}

1st DEGREE

2nd DEGREE



Data For Glass Fibre Filter

NO. POINTS = 65

X: MEAN= 33.46153846 ST.DEV.= 18.3916390
Y: MEAN= 3.491538462 ST.DEV.= 1.849446640

CORR.COEFF.= 0.996938679

Standard Error
.15 lpm cm⁻²

COEFFICIENTS

B(0)= 0.1370
B(1)= 0.1003

1st DEGREE

R SQUARE = 0.993886729

COEFFICIENTS

B(0)= -0.1233
B(1)= 0.1202
B(2)= -0.0003

2nd DEGREE

R SQUARE = 0.996445111

Data For Glass Fibre Filter

NO. POINTS = 65

X: MEAN= 33.46153846 ST.DEV.= 18.3916396
Y: MEAN= 3.491538462 ST.DEV.= 1.849446898

CORR.COEFF.= 0.996938679

Standard Error
.15 lpm cm⁻²

COEFFICIENTS

B(0)= 0.1370
B(1)= 0.1003

1st DEGREE

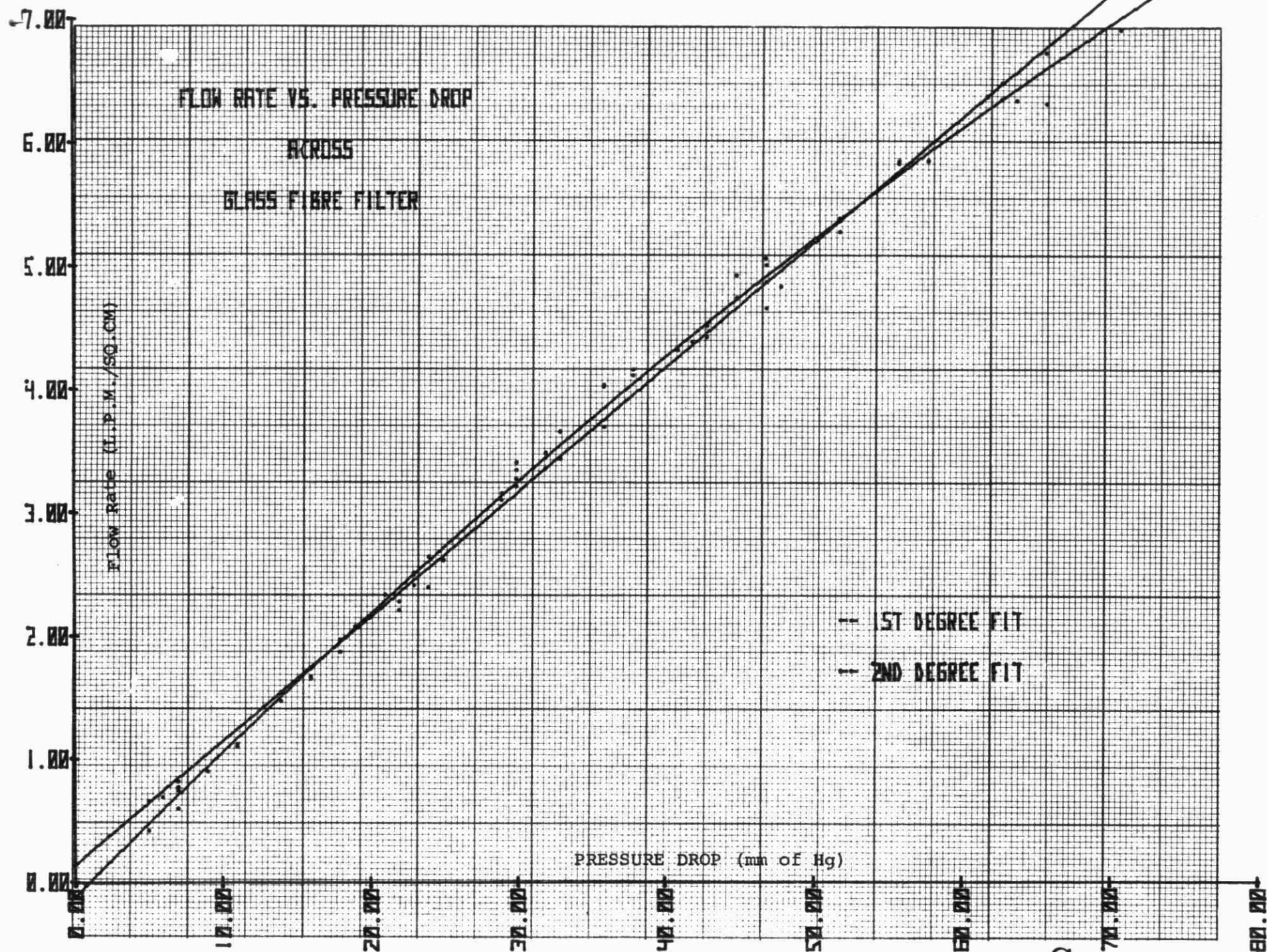
R SQUARE = 0.993886729

COEFFICIENTS

B(0)= -6.1293
B(1)= 0.1202
B(2)= -0.0003

2nd DEGREE

R SQUARE = 0.996445112



Data For Whatman Type 40 Filter

NO. POINTS = 5

X: MEAN= 210.2 ST.DEV.= 129.582792
Y: MEAN= 3.24 ST.DEV.= 1.780449381

CORR.COEFF.= 0.995511348

COEFFICIENTS

B(0)= 0.3648
B(1)= 0.0137

R SQUARE = 0.991042844

NO. POINTS = 5

X: MEAN= 210.2 ST.DEV.= 129.582792
Y: MEAN= 3.24 ST.DEV.= 1.780449381

CORR.C . = 0.995511348

COEFFICIENTS

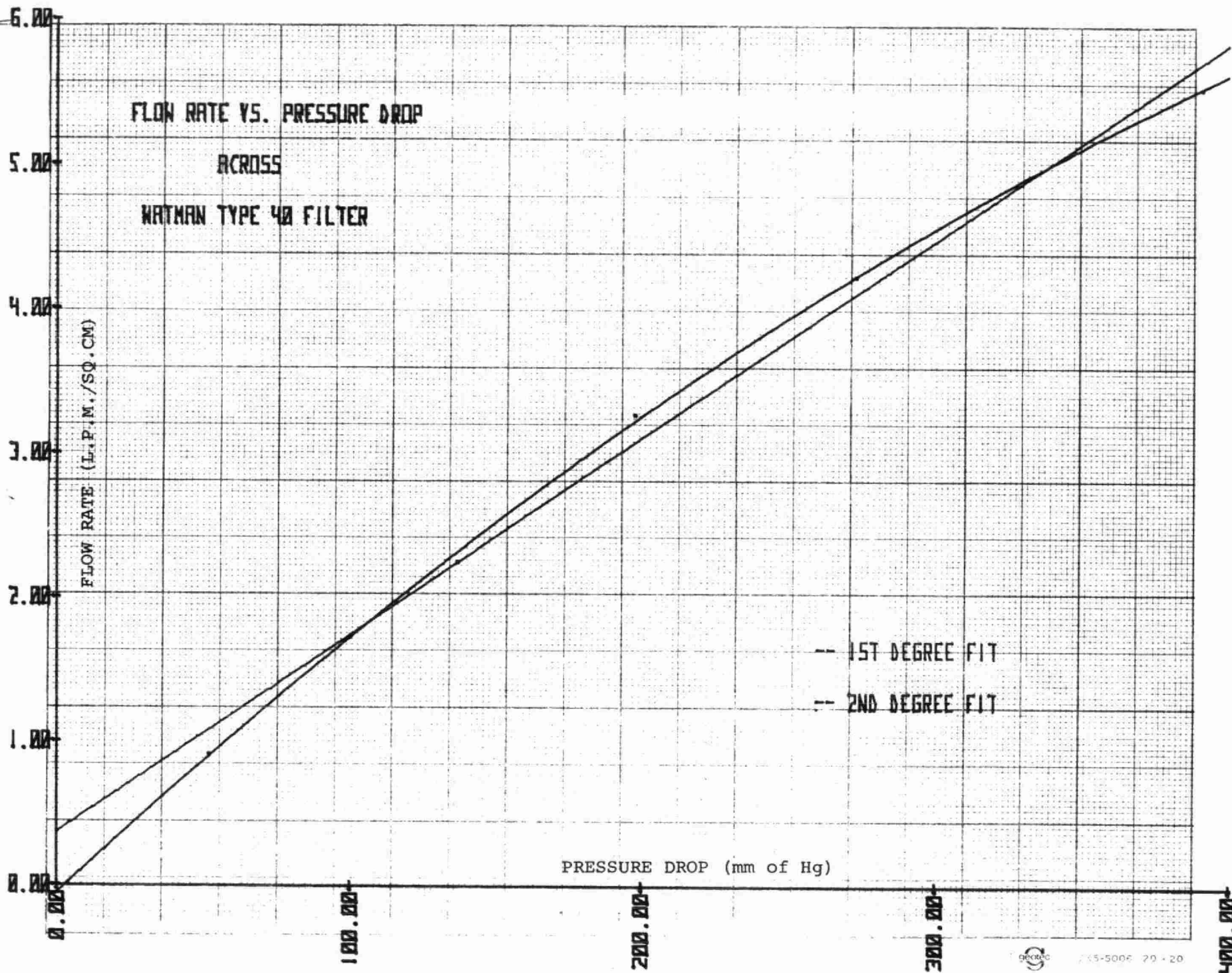
B(0)= -0.0602
B(1)= 0.0189
B(2)= -0.0000

R SQUARE = 0.999521366

1st DEGREE

Standard Error
Y on X
.2 lpm cm⁻²

2nd DEGREE



Data For Whatman Type "41" Filter

NO. POINTS = 15

X: MEAN= 30.788 ST.DEV.= 18.14044503
Y: MEAN= 4.441333333 ST.DEV.= 2.100846315

CORR.COEFF.= 0.993280444

COEFFICIENTS

B(0)= 0.8997
B(1)= 0.1150

R SQUARE = 0.986606040

Standard error
Y on X
.25 lpm cm⁻²

1st DEGREE

NO. POINTS = 15

X: MEAN= 30.788 ST.DEV.= 18.14044503
Y: MEAN= 4.441333333 ST.DEV.= 2.100846315

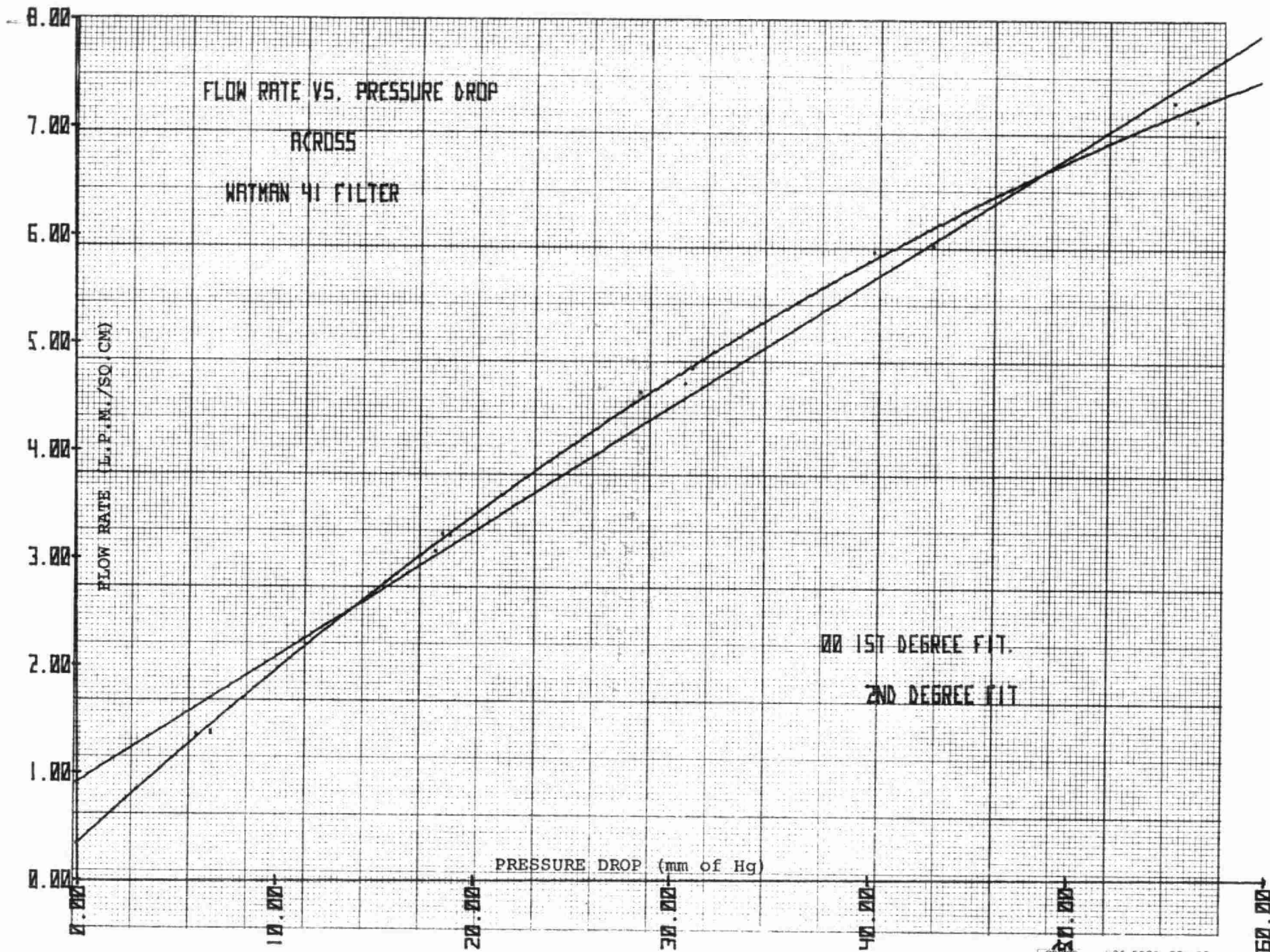
CORR.COEFF.= 0.993280444

COEFFICIENTS

B(0)= 0.3267
B(1)= 0.1675
B(2)= -0.0008

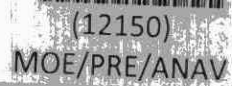
R SQUARE = 0.998529170

2nd DEGREE





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